PHY-901 Advanced Quantum Mechanics

Credit Hours: 3-0

Prerequisite: Quantum Mechanics

Course Objectives:

This course introduces students to topics that are traditionally left out in an introductory quantum mechanics course, such as, many-body quantum mechanics, second quantization, quantum fluids Bose-Einstein condensation and selected topics of relativistic quantum mechanics.

Core Contents:

The main contents of this course include the many-body quantum mechanics, system of identical particles, second quantization, symmetrization postulate, Elementary Theory of the Electron Gas, Hamiltonian Ground State Energy in the Hartree–Fock Approximation, quantum fluids and Bose-Einstein condensation. Moreover, it includes the selected topics of relativistic quantum mechanics, such as, the Klein–Gordon equation, the Dirac equation, Lorentz transformations and Lorentz covariance of the Dirac equation

Detailed Course Contents:

The detailed contents are given in the table below along with week-wise breakdown.

Textbooks:

1. F. Schwabl, Advanced Quantum Mechanics, 3^{rd} edition, Springer 2005.

Reference Books:

1. E. Manoukian, A wide spectrum, 1st edition Springer 2006.
2. J.J. Sakurai, Advanced Quantum Mechanics, Addison Wesley 1967.
3. P. Coleman, Introduction to many-body physics, Cambridge University Press 2011.

Weekly Breakdown		
Week	***Section***	***Topics***
1	1.1	Introduction to second quantization approach, Identical Particles, Many-Particle States, and Permutation Symmetry
2	1.1, 1.2	States and Observables of Identical Particles, Examples, Completely Symmetric and Antisymmetric States
3	1.3	Bosons, States, Fock Space, Creation and Annihilation Operators, The Particle-Number Operator, General Single- and Many-Particle Operators
4	1.4	Fermions, States, Fock Space, Creation and Annihilation Operators Single- and Many-Particle Operators
5	1.5, 1.6	Transformations Between Different Basis Systems, Field Operators, Field Equations, Momentum Representation, Momentum Eigenfunctions and the Hamiltonian, Fourier Transformation of the Density, The Inclusion of Spin
6	2.1	Noninteracting Fermions, The Fermi Sphere, Excitations, Single-Particle Correlation Function, Pair Distribution Function, Pair Distribution Function, Density Correlation Functions, and Structure Factor
7	2.2	Ground State Energy and Elementary Theory of the Electron Gas, Hamiltonian Ground State Energy in the Hartree–Fock Approximation, Modification of Electron Energy Levels due to the Coulomb Interaction
8	2.3, 3.1	Hartree–Fock Equations for Atoms,Free Bosons, Pair Distribution Function for Free Bosons, Two-Particle States of Bosons
9	3.2	Weakly Interacting, Dilute Bose Gas, Quantum Fluids and Bose–Einstein Condensation, Bogoliubov Theory of the Weakly Interacting Bose Gas, Superfluidity
10	4.1,4.2,4.3, 4.4,4.5	Scattering and Response, Density Matrix, Correlation Functions, Dynamical Susceptibility, Dispersion Relations,

		Spectral Representation
11	4.6,4.7,4.8,4.9	Fluctuation–Dissipation Theorem, Examples of Applications, Symmetry Properties, General Symmetry Relations, Symmetry Properties of the Response Function for Hermitian Operators, Sum Rules
12	5.1, 5.2	Introduction to Relativistic Wave Equation, The Klein–Gordon Equation (Derivation by Means of the Correspondence Principle, The Continuity Equation, Free Solutions of the Klein–Gordon Equation)
13	5.3	Dirac Equation, Derivation of the Dirac Equation, The Continuity Equation, Properties of the Dirac Matrices, The Dirac Equation in Covariant Form, Nonrelativistic Limit and Coupling to the Electromagnetic Field
14	6.1,6.2	Lorentz Transformations, Lorentz Covariance of the Dirac Equation (Lorentz Covariance and Transformation of Spinors, Determination of the Representation $S(\Lambda)$, Further Properties of S, Transformation of Bilinear Forms, Properties of the γ Matrices)
15	6.3	Solutions of the Dirac Equation for Free Particles, Spinors with Finite Momentum, Orthogonality Relations and Density, Projection Operators